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November 27, 2000

Assistant Commissioner for Patents  
Washington, D.C. 20231  
U.S.A.

Sir:

**Re: New United States Patent Application**

**Title: METHOD AND APPARATUS FOR  
EQUALIZATION ACROSS PLURAL  
DATA CHANNELS**

**Inventor(s): Roland A. SMITH and Kim B. ROBERTS**

**Assignee: Nortel Networks Limited**

**Our File: 9-13528-131US KD/bm**

Transmitted herewith for filing is the patent application of:

**INVENTOR(S): Roland A. SMITH and Kim B. ROBERTS**

**TITLE OF THE INVENTION:**

**METHOD AND APPARATUS FOR OPTICAL  
EQUALIZATION ACROSS PLURAL DATA  
CHANNELS**

The following documents are enclosed:

- a) Specification/Claims/Abstract with Declaration/Power of Attorney
- b) Assignment in favor of Nortel Networks Limited with Recordation Form PTO-1595
- c) Formal Drawings (3 Sheets - Figs. 1 - 3)
- d) Information Disclosure Statement with PTO Form 1449

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ARE PARTNERS

November 27, 2000

e) Our cheque No. 006912 and Fee Transmittal Form  
PTO/SB/17, covering:

Filing Fee	\$ 710.00
Recording of Assignment	\$ 40.00
<b>Total Number of Claims:</b>	<b>49</b>
Independent claims in excess of 3 (2 @ \$80)	\$ 160.00
Claims in excess of 20 (29 @ \$18)	\$ <u>522.00</u>
Total	\$1,432.00

The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to our Account No. 19-5113.

Please note that the address of the agents for the applicant in this matter should be the Montreal address identified in the enclosed Declaration/Power of Attorney. Correspondence may be directed to Kent Daniels at the Montreal address of Swabey Ogilvy Renault.

Respectfully submitted



Kent Daniels  
Reg. No. 44,206  
Agent of Record  
Encls.

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# FEE TRANSMITTAL for FY 2001

Patent fees are subject to annual revision.

TOTAL AMOUNT OF PAYMENT (\$ ) 1,432

## Complete if Known

Application Number  
 Filing Date 27 November 2000  
 First Named Inventor Roland A. Smith  
 Examiner Name  
 Group Art Unit  
 Attorney Docket No. 9-13528-131US KD/bm

## METHOD OF PAYMENT

1. ☐ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number 19-5113  
 Deposit Account Name Swabey Ogilvy Renault

- ☒ Charge Any Additional Fee Required  
 Under 37 CFR 1.16 and 1.17  
☐ Applicant claims small entity status.  
 See 37 CFR 1.27

2. ☒ Payment Enclosed:

☒ Check ☐ Credit card ☐ Money Order ☐ Other

## FEE CALCULATION

### 1. BASIC FILING FEE

Large Entity	Small Entity	Fee	Fee Description	Fee Paid
Code (\$)	Code (\$)			
101 710	201 355		Utility filing fee	710
105 320	205 190		Design filing fee	
107 490	207 245		Plant filing fee	
108 710	208 355		Reissue filing fee	
114 150	214 75		Provisional filing fee	

SUBTOTAL (1) (\$ ) 710.00

### 2. EXTRA CLAIM FEES

Total Claims	Extra Claims	Fee from below	Fee Paid
48	-20** = 28	X 16	= 448
5	-3** = 2	X 80	= 160
Multiple Dependent			= 0

### Large Entity Small Entity

Fee	Fee	Fee Description
Code (\$)	Code (\$)	
103 18	203 9	Claims in excess of 20
102 80	202 40	Independent claims in excess of 3
104 270	204 135	Multiple dependent claim, if not paid
109 80	209 40	** Reissue independent claims over original patent
110 18	210 9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) (\$ ) 682

\*\*for number previously paid, if greater; For Reissues, see above

## FEE CALCULATION (continued)

### 3. ADDITIONAL FEES

Large Entity	Small Entity	Fee	Fee Description	Fee Paid
Code (\$)	Code (\$)			
105 130	205 65		Surcharge - late filing fee or oath	
127 50	227 25		Surcharge - late provisional filing fee or cover sheet	
139 130	139 130		Non-English specification	
147 2,520	147 2,520		For filing a request for <i>ex parte</i> reexamination	
112 920*	112 920*		Requesting publication of SIR prior to Examiner action	
113 1,840*	113 1,840*		Requesting publication of SIR after Examiner action	
115 110	215 55		Extension for reply within first month	
116 390	216 195		Extension for reply within second month	
117 890	217 445		Extension for reply within third month	
118 1,390	218 695		Extension for reply within fourth month	
128 1,890	228 945		Extension for reply within fifth month	
119 310	219 155		Notice of Appeal	
120 310	220 155		Filing a brief in support of an appeal	
121 270	221 135		Request for oral hearing	
138 1,510	138 1,510		Petition to institute a public use proceeding	
140 110	240 55		Petition to revive - unavoidable	
141 1,240	241 620		Petition to revive - unintentional	
142 1,240	242 620		Utility issue fee (or reissue)	
143 440	243 220		Design issue fee	
144 600	244 300		Plant issue fee	
122 130	122 130		Petitions to the Commissioner	
123 50	123 50		Petitions related to provisional applications	
126 240	126 240		Submission of Information Disclosure Stmt	
581 40	581 40		Recording each patent assignment per property (times number of properties)	40
146 710	246 355		Filing a submission after final rejection (37 CFR § 1.129(a))	
149 710	249 355		For each additional invention to be examined (37 CFR § 1.129(b))	
179 710	279 355		Request for Continued Examination (RCE)	
169 900	169 900		Request for expedited examination of a design application	

Other fee (specify)

\*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) (\$ ) 40

## SUBMITTED BY

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Burden Hour Statement: This form is estimated to take 0.2 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, Washington, DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Washington, DC 20231.

METHOD AND APPARATUS FOR EQUALIZATION ACROSSPLURAL DATA CHANNELSCROSS-REFERENCE TO RELATED APPLICATIONS

This is the first application filed for the present  
5 invention.

MICROFICHE APPENDIX

Not Applicable.

TECHNICAL FIELD

The present invention relates to communications  
10 networks, and in particular to a method and apparatus for  
signal equalization across multiple data channels of an  
optical communications network.

BACKGROUND OF THE INVENTION

In the modern communications network space, signal  
15 reach and spectral density are important factors in overall  
network cost. Assuming other factors to be equal,  
increases in either signal reach or spectral density tend  
to reduce overall network cost and are thus very attractive  
to network service providers.

Signal reach is the distance that an optical signal  
20 can be transmitted through a fiber, before conversion to  
electronic form is required to perform signal regeneration.  
Using suitable optical amplifiers and optical processing  
techniques, between 10 and 20 fiber spans (of 40-80 km  
25 each) can be traversed by an optical signal before  
optical/electrical conversion and regeneration are  
required.

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Spectral density, which is normally expressed in terms of bits/sec/Hz (b/s/Hz), is a measure of the extent to which the theoretical maximum bandwidth capacity of an optical channel is utilized. This value is generally  
5 determined by dividing the line rate (in bits/sec.) of a channel by the optical frequency (in Hz) of that channel. A spectral density of 1 indicates that, for a given channel, the line rate and optical frequency are equal, so that each carries a bit of information. Existing  
10 telecommunications systems commonly operate at line rates of approximately 2.5Gb/s to 40Gb/s. At a line rate of 10Gb/s, current Wavelength Division Multiplexed (WDM) (or Dense Wave Division Multiplexed (DWDM)) transmission systems achieve a spectral density of approximately 0.1  
15 b/s/Hz. If the line rate is increased to 40Gb/s, the spectral density increases to approximately 0.4b/s/Hz, illustrating the advantages of increasing the line rate.

However, there is a trade-off involved in using increased line rates to improve spectral density. In  
20 particular, increased line rates typically result in a reduction in signal reach. For example, with the use of appropriate optical amplifiers, a signal reach of 2500km has been demonstrated at a line rate of 2.488Gb/s (equivalent to a SONET/SDH OC-48 signal). At a line rate  
25 of 40Gb/s, the signal reach drops to approximately 1000 Km. This reduction in signal reach is explained by the fact that, as the line rate increases non-linear optical effects (e.g. self-phase modulation, optical dispersion, etc.) become progressively more significant, and cause increased  
30 bit error rates. In general, in order to keep the bit error rate below a tolerable threshold the distance that an optical signal is transmitted through a fiber before conversion to electronic form must be reduced.

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Typically, the performance of optical fibers and amplifiers is non-linear across an optical spectrum of interest. This non-linear performance is manifested in, among other things, variations in the signal-to-noise ratio and signal gain ( $Q$ ) of each channel. These variations tend to accumulate with each amplification stage and thus can become very large over the 15-20 spans of a fiber link. Since the length of each fiber link (i.e. the length of each span, and the number of spans before conversion to electronic form) is governed by the bit error rate of the lowest-performing channel, such high  $Q$  variations mean that most of the (higher performing) channels must operate with a shorter signal reach than would be indicated by their individual bit error rates. Accordingly, it is desirable to equalize performance across the channels.

Various methods of optical gain equalization are known in the art. See, for example, United States Patent No. 6,091,538 issued to Takeda et al. on July 18, 2000 and entitled Gain Equalizing Apparatus; and United States Patent No. 6,097,535 issued to Terahara on August 1, 2000 and entitled Method for Optical Amplification and System for Carrying Out the Method. Both of these patents use a variation of known Adaptive Optical Equalization techniques, in which the detected signal power is used to dynamically adjust the gain of an optical amplifier, to thereby minimize variations in the gain across multiple channels. Other known techniques involve the use of static or dynamic gain equalization filters, which operate by attenuating the optical signal power on channels with relatively high gain.

While each of the above methods are capable of reducing variations in gain, the physical properties of

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installed equalization devices are subject to a certain amount of variation, resulting in an unavoidable equalization error, typically on the order of approximately  $\pm 0.2\text{dB}$ . Over a link comprising 20 spans, this optical  
5 equalization error can accumulate to produce an uncompensated variation across the channels of as much as  $\pm 4\text{dB}$ .

Accordingly, a method and apparatus that enables maximized signal reach by providing effective equalization  
10 across multiple channels remains highly desirable.

#### **SUMMARY OF THE INVENTION**

Accordingly, an object of the present invention is to provide a method an apparatus for conveying data signals through a multi-channel WDM network in which the effects of  
15 performance variations across the channels are effectively compensated.

Accordingly, an aspect of the present invention provides a method of optical equalization across N (an integer,  $N > 1$ ) channels of a multi-channel link of a  
20 communications network. Each one of M (an integer,  $M > 1$ ) parallel data signals are distributed across the N channels of the link, such that a substantially equal portion of each data signal is conveyed through each one of the N channels. Respective bit-streams received over the N  
25 channels are processed to recover the M data signals. As a result, performance variations between the N channels are optically equalized by averaging within each of the M data signals.

A further aspect of the present invention provides  
30 a method of conveying M (an integer,  $M > 1$ ) data signals

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across a multi-channel link of a communications network. At a transmitting end of the link, each one of the M data signals are distributed across the N channels of the link, such that a substantially equal portion of each data signal is conveyed through each one of the N channels. At a receiving end of the link, respective bit-streams received over the N channels are processed to recover the M data signals.

Another aspect of the present invention provides a system for equalization across N (an integer,  $N > 1$ ) channels of a multi-channel link of a communications network. The system comprises: means for distributing each one of M (an integer,  $M > 1$ ) parallel data signals across the N channels of the link, such that a substantially equal portion of each data signal is conveyed through each one of the N channels; and means for processing respective bit-streams received over the N channels to recover the M data signals. As a result, performance variations between the N channels are optically equalized by averaging within each of the M data signals.

Another aspect of the present invention provides an apparatus for enabling equalization across N (an integer,  $N > 1$ ) channels of a multi-channel link of a communications network, the apparatus comprising means for distributing each one of M (an integer,  $M > 1$ ) parallel data signals across the N channels of the link, such that a substantially equal portion of each data signal is conveyed through each one of the N channels.

Another aspect of the present invention provides a apparatus for enabling equalization across N (an integer,  $N > 1$ ) channels of a multi-channel link of a communications network, in which a substantially equal portion of each one

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of M (an integer,  $M > 1$ ) data signal is conveyed through each one of the N channels, the apparatus comprising means for processing respective bit-streams received over the N channels to recover the M parallel data signals.

- 5           Each data signal may be a Forward Error Correction (FEC) encoded data stream.

- 10           In embodiments of the invention, each one of the M data signals may be distributed across the N channels of the link by: substantially evenly dividing each one of the M data signals into N respective sub-signals; and interleaving one sub-signal of each data signal into a respective one of the N channels. Division of each data signal may be accomplished, for each data signal, by: partitioning the data signal into a sequential series of data units having a predetermined size; and forwarding each successive data unit, in turn, to a respective one of the N sub-signals. Each data unit may have a size of one or more bits.

- 20           In embodiments of the invention, a respective unique identifier is inserted into a predetermined location of each sub-signal, prior to interleaving the sub-signal into a respective one of the N channels. In such cases, processing a bit-stream received over a respective channel may comprise searching the bit stream to locate the unique identifier.

- 30           One sub-signal of each data signal may be interleaved into a respective one of the N channels using a conventional sequential interleaving process. Thus, a data unit can be sequentially selected from one sub-signal of each data signal, and each selected data unit then forwarded, in turn, to the channel.

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In embodiments of the invention, a respective bit-stream received over each one of the N channels may be processed by: dividing each bit-stream to recover a respective sub-signal of each data signal; and interleaving  
5 respective recovered sub-signals of each data signal to recover each one of the M data signals. Division of each bit-stream may be accomplished, for each bit-stream, by: partitioning the bit-stream into a sequential series of data units having a predetermined size; and forwarding each  
10 successive data unit to a respective one of N recovered sub-streams.

In cases where each sub-signal includes a predetermined unique identifier, partitioning the bit-stream may be accomplished by searching the bit-stream to  
15 locate the unique identifier; and extracting one or more data units associated with the unique identifier from the bit-stream.

A conventional sequential interleaving process may be used to interleave respective recovered sub-signals of  
20 each data signal to recover each one of the M data signals. Thus, for each one of the M data signals, one data unit can be sequentially selected from each sub-signal of the data signal, successively selected data units are then appended to recover the original data signal.

An advantage of the present invention resides in the recognition that it is the bit error rate of data signals being transported through a fiber link, rather than the bit error rate of any one channel, that should be determinative of link length. By distributing each data  
30 signal evenly across two or more channels, the bit error rate for the signal is an average of the bit error rates of each involved channel. Thus the impact of any variations

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in channel performance is shared equally by each of the data streams, thereby diluting the effects of the lowest-performing channel and consequently allowing an increase in link length beyond that which would be indicated by the bit error rate of the lowest-performing channel.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Further features and advantages of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

Fig. 1. is a block diagram schematically illustrating a communications network in which an embodiment of the present invention may be deployed;

Fig. 2 is a block diagram schematically illustrating operation of a signal distribution unit 12 in accordance with an embodiment of the present invention, the signal distribution unit 12 being adapted to operate in a transmitting end node of a fiber link; and

Fig. 3 is a block diagram schematically illustrating operations of a signal regeneration circuit in accordance with an embodiment of the present invention, the signal regeneration circuit being adapted to operate in a receiving end node of a fiber link.

It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

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**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

The present invention provides a method and apparatus for optical equalization to improve signal reach by distributing two or more data signals across two or more  
5 channels of an optical link. At a receiving end of the optical link, data-streams conveyed through each of the channels are processed to recover the original data signals.

FIG. 1 is a schematic diagram of a communications  
10 network 2 in which the present invention may be deployed. The network 2 includes a plurality of nodes 4a-e (which may be, for example, routers, cross-connects, regenerators or Add-Drop-multiplexors (ADMs)) interconnected by fibre links 6a-e. Each of the nodes 4a-e are preferably  
15 electro-optical nodes configured for wave division multiplex (WDM) and/or dense wave division multiplex (DWDM) transport of data traffic. For the purposes of the present invention, optical signals received at a node 4 from a fiber link 6 are assumed to be de-multiplexed and converted  
20 to electrical signals for signal regeneration and/or routing. Each fibre link 6a-e includes one or more fibre spans 8 coupled together by optical amplifiers 10. For the purposes of the present invention, optical signals received at an optical amplifier 10 from a fiber span 8 are assumed  
25 to be optically de-multiplexed and amplified without optical to electrical conversion.

Fig. 2 is a block diagram schematically illustrating operations of a signal distribution unit 12 in accordance with an aspect of the present invention. The  
30 signal distribution unit 12 may be implemented as hardware and/or software within each transmitting end node 4a-e. In a hardware implementation, the signal distribution unit 12

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may be an application specific integrated circuit (ASIC), or may be incorporated into a larger ASIC such as, for example, a forward error correction (FEC) ASIC. In either case, the signal distribution unit 12 operates to

5 distribute M (where M is an integer, and  $M > 1$ ) data signals 14 (in the example shown in Fig. 2,  $M=3$ ) across N (where N is an integer, and  $N > 1$ ) channels 16 (in the example shown in Fig. 2,  $N=4$ ). The channels 16 can then be routed through conventional signal transmission circuits

10 (not shown) which perform electro/optical conversion and optical multiplexing of the channels 16 into the fiber links 6a-e in a manner known in the art. For example, known signal multiplexing methods may be utilized to multiplex the channels 16 onto respective different wavelengths

15 within the same WDM or DWDM fiber, respective wavelengths within two or more WDM or DWDM fibers, or respective single-wavelength fibers. With any of these approaches, it is also possible to use a Code Division Multiple Access (CDMA) encoding system to combine and transmit data signals

20 within the channels 16.

In general, the signal distribution unit 12 comprises at least M signal dividers 18a-c, and at least N interleavers 20a-d. Each signal divider 18a-c divides a respective data signal 14a-c into N sub-streams 22 (i.e.

25 one sub-stream 22 for each channel 16). As illustrated in Fig. 2, one method by which this may be accomplished is to divide each data signal 14 into a sequential series of data units 24 of a predetermined length. The length of each data unit is arbitrary, and may be as short as a single

30 bit. The signal divider 18 then forwards each successive data unit 24 of a respective data signal 14 to a respective one of the sub-streams 22, in turn, so that each sub-stream 22 includes a substantially equal proportion of

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the original data signal 14. Each sub-stream 22 from a data signal 14 is forwarded to a respective one of the interleavers 20a-b, so that each channel 16 carries one sub-stream 22 from (and thus a substantially equal portion of) each data signal 14.

Each interleaver 20, which may be implemented in hardware and/or software, comprises a sub-stream processor 19 and a sequential interleaving multiplexor 21. The sub-stream processor operates to insert a unique sub-stream identifier into each of the sub-streams 22 received by the interleaver 20, prior to their being interleaved into a respective channel 16. The sub-stream identifier serves to enable successful discrimination and separation of the sub-streams from a respective channel 16 at a downstream node 4. The sub-stream identifier preferably comprises a unique, n-bit word, which is inserted into a respective sub-stream 22 at a predetermined frequency. The length (i.e. number n of bits) of the sub-stream identifier, and the insertion frequency are implementation specific, and may be varied as required. In order to provide reliable identification of the sub-stream identifier at a downstream node 4, a sub-stream identifier of at least 10 bits is preferred. In a high-noise environment, a sub-stream identifier of 20 bits or more may be required in order to obtain reliable separation of the sub-streams 22. Additionally, it is preferable to ensure that the insertion frequency of the sub-stream identifier is sufficiently high to enable accurate compensation for noise and signal jitter, but should not be so high as to introduce an unnecessary overhead into the sub-stream. In general, an insertion frequency of about 8kHz should yield satisfactory results in most cases.

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The sequential interleaving multiplexor 21 operates in a manner known in the art to interleave the sub-streams 22 (including their respective sub-stream identifiers) into a respective channel 16. The order in which bits of each sub-stream 22 are interleaved into a  
5       respective channel 16 is predetermined, to facilitate recovery of the original data signals 14 at a receiving end node 46.

In the embodiment illustrated in Fig. 2, the signal  
10       distribution unit 12 is configured to distribute  $M=3$  data signals 14a-c across  $N=4$  channels 16a-d. Thus the signal distribution unit 12 of Fig. 2 comprises  $M=3$  signal dividers 18a-c, each of which divides its respective data signal 14 into  $N=4$  sub-streams 22. Similarly,  $N=4$   
15       interleavers 20a-d are provided for interleaving respective sub-streams 22 from each data signal 14 into a respective one of the channels 16. Thus, interleaver 20a operates to interleave sub-stream U1 of each of incoming data signals 14a-c to create a serial composite data-stream 26a  
20       on channel 16a. Interleaver 20b operates to interleave sub-stream U2 of each of incoming data streams 14a-c to create a serial composite data-stream 26b on channel 16b. Interleaver 20c operates to interleave sub-stream U3 of each of data streams 14a-c to create a serial composite  
25       data-stream 26c on channel 16c. Finally, interleaver 20d operates to interleave sub-stream U4 of each of data signals 14a-c to create a serial composite data-stream 26d on channel 16d.

As mentioned above, the number ( $M$ ) of data  
30       signals 14, and the number ( $N$ ) of channels are arbitrary within a range governed by physical constraints of the networks. Thus, it will be appreciated that the signal

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distribution unit 12 of Fig. 2 may be equipped with a number of signal dividers 18 required to handle a desired number of data signals 14. Similarly, the distribution unit 12 is equipped with a number of interleavers 20  
5 interconnected with the signal dividers 18, to distribute data signals 14 across a desired number of channels 16. Advantages of the present invention may be obtained with distribution across as few as two channels 16. However, in practice, it will generally be preferable to distribute 2  
10 or more signals across a larger number of channels which, depending on the specifics of a particular implementation, may be less than, equal to, or greater than the number of data signals 14. The method and apparatus of the invention are transparent to the protocol of the data signals 14, and  
15 so the protocol may be selected as required for a specific implementation. For example, if desired the data signals 14 may be forward error correction (FEC) encoded SONET/SDH signals.

The signal distribution process described above  
20 with respect to Fig. 2 is fully reversible to recover the original data signals 14. Fig. 3 is a block diagram of a signal recovery unit 28, which is implemented in each receiving end node 4a-e. The signal recovery unit 28 shown in Fig. 3 can be implemented in hardware and/or software  
25 downstream of conventional optical demultiplexing and opto/electrical conversion circuits, which operate to optically demultiplex the channels 16a-d from a fiber link 6, and convert each composite data-stream 26a-d into electronic form for processing. Conventional clock  
30 recovery and signal regeneration circuits (not shown) may also be implemented upstream of the signal recovery circuit 28 shown in Fig. 3.

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The signal recovery unit 28 generally includes at least N parallel elastic buffers 30a-d, each of which is arranged to receive a respective composite data-stream 26 from one of the channels 16. The elastic buffers 30a-d cooperate to de-skew the composite data-streams 26a-d, and thus compensate for propagation delay differences between each of the channels. Each of the de-skewed composite data-signals 26a-d is then passed to a respective framer 32 and demultiplexor 34. The framer 32 analyses the respective composite data-stream 26 to detect the sub-stream identifiers of each of the sub-streams 22 contained in the composite data-stream 26, and generates a synchronization signal which is used to control the operation of the respective demultiplexor 34. Using the synchronization signal, in combination with the known interleaving sequence of the interleavers 20a-d, each demultiplexor 30a-d operates to demultiplex its respective composite data-stream 26, to recover one sub-stream 22 of each data signal 14. The sub-streams 22 of each data signal 14 are forwarded (one from each demultiplexor 30) to a one of M multiplexors 32a-c which multiplex the sub-streams 22 to recover the respective data signals 14.

As shown in Figs. 2 and 3, a data stream 14 (which may be FEC encoded) is evenly divided into sub-streams 22, which are interleaved and transmitted through a fiber link within respective parallel channels 16. At a receiving end node 4b, the sub-streams 22 are demultiplexed from their respective channels 16 and then multiplexed together to recover the original data signals 14. Between transmitting and receiving end nodes 4, each composite data-stream 26 transits a fiber link 6 within a respective one of the N channels 16. Consequently, each composite data-stream 26 is subject to optical amplification gain, attenuation,

dispersion and noise in accordance with the optical performance of the channel 16 through which it is conveyed. When the composite data-streams are demultiplexed, the respective sub-streams 22 express a bit error rate that is associated with the optical characteristics of the channel on which it was conveyed.

Multiplexing of the sub-streams 22 in the signal recovery circuit 28 by sub-stream multiplexers 32 yields a recovered data signal 14 having an aggregate bit error rate that approximates an average of the bit error rates of each channel 16 through which the composite data-streams 26 were transmitted. Since each of the transmitted data signals 14 are preferably equally distributed over the respective channels 16, this averaging of bit error rates affects each of the data signals 14 approximately equally. Thus, optical equalization across the N channels of the fiber link 6a is achieved by averaging the effects of optical performance variations across M parallel data signals conveyed through the link 6.

The present invention therefore provides a method and apparatus for achieving optical equalization across multiple channels of a multi-channel fibre link 6a, thereby extending signal reach by distributing the effect related to channel performance.

The embodiment(s) of the invention described above is(are) intended to be exemplary only. The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.

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**WE CLAIM:**

1. A method of equalization across  $N$  (an integer,  $N > 1$ ) channels of a multi-channel link of a communications network, comprising steps of:
  - a) distributing each one of  $M$  (an integer,  $M > 1$ ) data signals across the  $N$  channels of the link, such that a substantially equal proportion of each data signal is conveyed through each one of the  $N$  channels as a composite data-stream; and
  - b) processing the composite data-streams conveyed through the  $N$  channels to recover the  $M$  data signals;whereby performance variations between the  $N$  channels are equalized by averaging within each of the  $M$  data signals.
2. A method as claimed in claim 1, wherein each data signal is a Forward Error Correction (FEC) encoded data stream.
3. A method as claimed in claim 1, wherein the step of distributing each one of the  $M$  data signals across the  $N$  channels of the link comprises steps of:
  - a) dividing each one of the  $M$  data signals into  $N$  respective sub-streams of substantially equal length; and
  - b) interleaving the sub-streams into respective ones of the  $N$  channels.
4. A method as claimed in claim 3, wherein the step of dividing each data signal comprises a step of

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inserting a respective predetermined unique identifier into each sub-stream.

5. A method as claimed in claim 3, wherein the step of dividing each data signal comprises, steps of:
  - a) partitioning the data signal into a sequential series of data units having a predetermined length; and
  - b) forwarding each successive data unit, in turn, to a respective sub-stream.
6. A method as claimed in claim 5, wherein each data unit has a length of one or more bits.
7. A method as claimed in claim 5, wherein the step of interleaving one sub-stream of each data signal into a respective one of the N channels comprises using a sequential interleaving process to:
  - a) select a data unit from one sub-stream of each data signal in a predetermined order; and
  - b) forward each selected data unit, in turn, to the channel.
8. A method as claimed in claim 1, wherein the step of processing a composite data-stream conveyed through each of the N channels comprises steps of:
  - a) dividing each composite data-stream to recover respective sub-streams of each data signal; and
  - b) interleaving respective recovered sub-streams of each data signal to recover each one of the M data signals.

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9. A method as claimed in claim 8, wherein the step of dividing each composite data-stream comprises steps of:
- a) partitioning the composite data-stream into a sequential series of data units having a predetermined length; and
  - b) forwarding each successive data unit to a respective one of N recovered sub-streams.
10. A method as claimed in claim 9, wherein each sub-stream within the composite data stream includes a respective predetermined unique identifier, and the step of partitioning the composite data-stream comprises the steps of:
- a) searching the composite data-stream to locate a unique identifier; and
  - b) extracting one or more data units associated with the unique identifier from the composite data stream.
11. A method as claimed in claim 9, wherein each data unit has a length of one or more bits.
12. A method as claimed in claim 9, wherein the step of interleaving respective recovered sub-signals of each data signal to recover each one of the M data signals comprises using a sequential interleaving process to:
- a) select one data unit from each sub-signal of the data signal; and
  - b) append successively selected data units to recover the original data signal.

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13. A method of conveying M (an integer,  $M > 1$ ) data signals across a multi-channel link of a communications network, the method comprising steps of:
- a) at a transmitting end of the link, distributing each one of the M data signals across the N channels of the link, such that a substantially equal proportion of each data signal is conveyed through each one of the N channels as a composite data-stream; and
  - b) at a receiving end of the link, processing respective composite data-streams conveyed through the N channels to recover the M data signals.
14. A method as claimed in claim 13, wherein each data signal is a Forward Error Correction (FEC) encoded data stream.
15. A method as claimed in claim 13, wherein the step of distributing each one of the M data signals across the N channels of the link comprises steps of:
- a) dividing each one of the M data signals into N respective sub-streams of substantially equal lengths; and
  - b) interleaving one sub-stream of each data signal into a respective one of the N channels.
16. A method as claimed in claim 15, wherein the step of dividing each data signal comprises a step of inserting a respective predetermined unique identifier into each sub-stream.

17. A method as claimed in claim 15, wherein the step of dividing each data signal comprises, for each data signal, the steps of:
- a) partitioning the data signal into a sequential series of data units having a predetermined length; and
  - b) forwarding each successive data unit, in turn, to a respective one of the N channels.
18. A method as claimed in claim 17, wherein each data unit has a size of one or more bits.
19. A method as claimed in claim 17, wherein the step of interleaving one sub-signal of each data signal into a respective one of the N channels comprises using a sequential interleaving process to:
- a) select a data unit from one sub-signal of each data signal; and
  - b) forward each selected data unit, in turn, to the channel.
20. A method as claimed in claim 13, wherein the step of processing a composite data-stream received over each of the N channels comprises steps of:
- a) dividing each composite data-stream to recover respective sub-streams of each data signal; and
  - b) interleaving respective recovered sub-streams of each data signal to recover each one of the M data signals.

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21. A method as claimed in claim 20, wherein the step of dividing each composite data-stream comprises steps of:
- a) partitioning the composite data-stream into a sequential series of data units having a predetermined length; and
  - b) forwarding each successive data unit to a respective one of N recovered sub-streams.
22. A method as claimed in claim 21, wherein each sub-stream within the composite data stream includes a respective predetermined unique identifier, and the step of partitioning the composite data-stream comprises the steps of:
- a) searching the composite data-stream to locate a unique identifier; and
  - b) extracting one or more data units associated with the unique identifier from the composite data stream.
23. A method as claimed in claim 21, wherein each data unit has a length of one or more bits.
24. A method as claimed in claim 21, wherein the step of interleaving respective recovered sub-signals of each data signal to recover each one of the M data signals comprises using a sequential interleaving process to
- a) select one data unit from each sub-signal of the data signal; and
  - b) append successively selected data units to recover the original data signal.

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25. A system for of optical equalization across  $N$  (an integer,  $N > 1$ ) channels of a multi-channel link of a communications network, the system comprising:
- a) means for distributing each one of  $M$  (an integer,  $M > 1$ ) parallel data signals across the  $N$  channels of the link, such that a substantially equal proportion of each data signal is conveyed through each one of the  $N$  channels as a composite data-stream; and
  - b) means for processing respective composite data-streams conveyed through the  $N$  channels to recover the  $M$  data signals;
- whereby performance variations between the  $N$  channels are optically equalized by averaging within each of the  $M$  data signals.
26. A system as claimed in claim 25, wherein each data signal is a Forward Error Correction (FEC) encoded data stream.
27. A system as claimed in claim 25, wherein the means for distributing each one of the  $M$  data signals across the  $N$  channels of the link comprises:
- a) means for dividing each one of the  $M$  data signals into  $N$  respective sub-signals of substantially equal length; and
  - b) means for interleaving sub-signals into respective ones of the  $N$  channels.
28. A system as claimed in claim 27, wherein the means for dividing each data signal comprises means for

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inserting a respective predetermined unique identifier into each sub-stream.

29. A system as claimed in claim 27, wherein the means for dividing each data signal into sub-streams comprises:
- a) means for partitioning the data signal into a sequential series of data units having a predetermined length; and
  - b) means for forwarding each successive data unit, in turn, to a respective one of the N channels.
30. A system as claimed in claim 29, wherein each data unit has a length of one or more bits.
31. A system as claimed in claim 29, wherein the means for interleaving one sub-stream of each data signal into a respective one of the N channels comprises, for each channel, a sequential interleaving multiplexor adapted to:
- a) select a data unit from one sub-signal of each data signal; and
  - b) forward each selected data unit, in turn, to the channel.
32. A system as claimed in claim 25, wherein the means for processing a respective composite data-stream received over each of the N channels comprises:
- a) means for dividing each composite data-stream to recover respective sub-streams of each data signal; and

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- b) means for interleaving respective recovered sub-signals of each data signal to recover each one of the M data signals.
33. A system as claimed in claim 32, wherein the means for dividing each composite data-stream comprises:
- a) means for partitioning the bit-stream into a sequential series of data units having a predetermined size; and
- b) means for forwarding each successive data unit to a respective one of N recovered sub-streams.
34. A system as claimed in claim 33, wherein each sub-stream within the composite data stream includes a respective predetermined unique identifier, and the means for partitioning the composite data-stream comprises:
- a) means for searching the composite data-stream to locate a unique identifier; and
- b) means for extracting one or more data units associated with the unique identifier from the composite data stream.
35. A system as claimed in claim 33, wherein each data unit has a size of one or more bits.
36. A system as claimed in claim 33, wherein the means for interleaving respective recovered sub-signals of each data signal to recover each one of the M data signals comprises, for each data signal, a respective sequential interleaving multiplexor adapted to:

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- a) select one data unit from each sub-stream of the data signal; and
  - b) append successively selected data units in a predetermined order to recover the original data signal.
37. An apparatus for enabling optical equalization across  $N$  (an integer,  $N > 1$ ) channels of a multi-channel link of a communications network, the apparatus comprising means for distributing each of  $M$  (an integer,  $M > 1$ ) parallel data signals across the  $N$  channels of the link, such that a substantially equal portion of each data signal is conveyed through each one of the  $N$  channels.
38. An apparatus as claimed in claim 37, wherein each data signal is a Forward Error Correction (FEC) encoded data stream.
39. An apparatus as claimed in claim 37, wherein the means for distributing each of the  $M$  data signals across the  $N$  channels of the link comprises:
- a) means for dividing each one of the  $M$  data signals into  $N$  respective sub-streams of substantially equal length; and
  - b) means for interleaving the sub-streams into respective ones of the  $N$  channels.
40. An apparatus as claimed in claim 39, wherein the means for dividing each data signal comprises means for inserting a respective predetermined unique identifier into each sub-stream.

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41. An apparatus as claimed in claim 39, wherein the means for dividing each data signal into sub-streams comprises:
- a) means for partitioning the data signal into a sequential series of data units having a predetermined length; and
  - b) means for forwarding each successive data unit, in turn, to a respective one of the N channels.
42. An apparatus as claimed in claim 41, wherein each data unit has a length of one or more bits.
43. An apparatus as claimed in claim 41, wherein the means for interleaving one sub-stream of each data signal into a respective one of the N channels comprises, for each one of the N channels, a sequential interleaving multiplexor adapted to:
- a) select a data unit from one sub-signal of each data signal; and
  - b) forward each selected data unit, in turn, to the channel.
44. An apparatus for enabling optical equalization across N (an integer,  $N > 1$ ) channels of a multi-channel link of a communications network, in which a substantially equal portion of each one of M (an integer,  $M > 1$ ) data signal is conveyed through each one of the N channels, the apparatus comprising means for processing respective composite data-streams received over the N channels to recover the M parallel data signals.

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45. An apparatus as claimed in claim 44, wherein the means for processing a respective composite data stream received over each of the N channels comprises:
- a) means for dividing each composite data-stream to recover respective sub-streams of each data signal; and
  - b) means for interleaving respective recovered sub-streams of each data signal to recover each one of the M data signals.
46. An apparatus as claimed in claim 45, wherein the means for dividing each composite data-stream comprises:
- a) means for partitioning the bit-stream into a sequential series of data units having a predetermined size; and
  - b) means for forwarding each successive data unit to a respective one of N recovered sub-streams.
47. An apparatus as claimed in claim 46, wherein each sub-stream within the composite data stream includes a respective predetermined unique identifier, and the means for partitioning the composite data-stream comprises:
- a) means for searching the composite data-stream to locate a unique identifier; and
  - b) means for extracting one or more data units associated with the unique identifier from the composite data stream.

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48. An apparatus as claimed in claim 46, wherein each data unit has a size of one or more bits.
49. An apparatus as claimed in claim 46, wherein the means for interleaving respective recovered sub-signals of each data signal to recover each one of the M data signals comprises, for each one of the M data signals, a respective sequential interleaving multiplexor adapted to:
- a) sequentially select one data unit from each sub-stream of the data signal; and
  - b) append successively selected data units in a predetermined order to recover the original data signal.

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**ABSTRACT OF THE DISCLOSURE**

Optical equalization across  $N$  (an integer,  $N > 1$ ) channels of a multi-channel link of a communications network, is accomplished by averaging effects of optical performance variations within each of the  $M$  (an integer,  $M > 1$ ) parallel data signals. At a transmitting end node of the link, each one of the  $M$  data signals are distributed across the  $N$  channels of the link. Thus a substantially equal portion of each data signal is conveyed through the link in each one of the  $N$  channels. At a receiving end node of the link, respective bit-streams received over the  $N$  channels to are processed recover the  $M$  data signals. As a result, bit error rates of the bit-streams received through each channel are averaged across the  $M$  data signals, all of which therefore have a substantially equal aggregate bit error rate.

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Figure 1

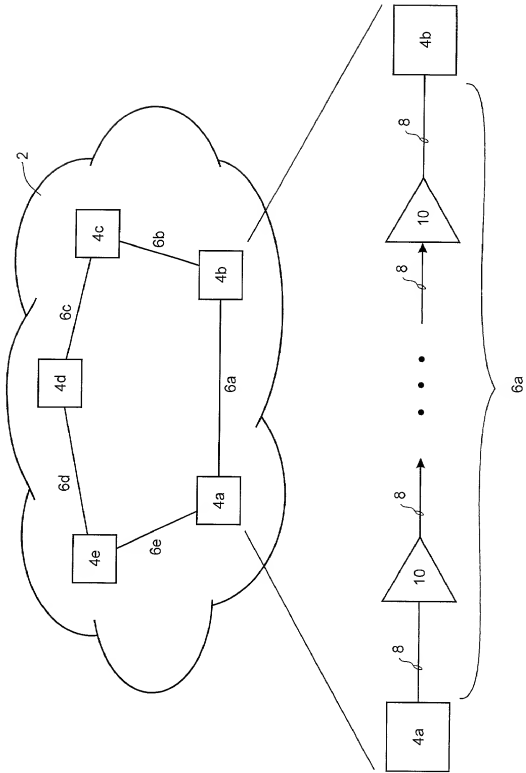


Figure 2

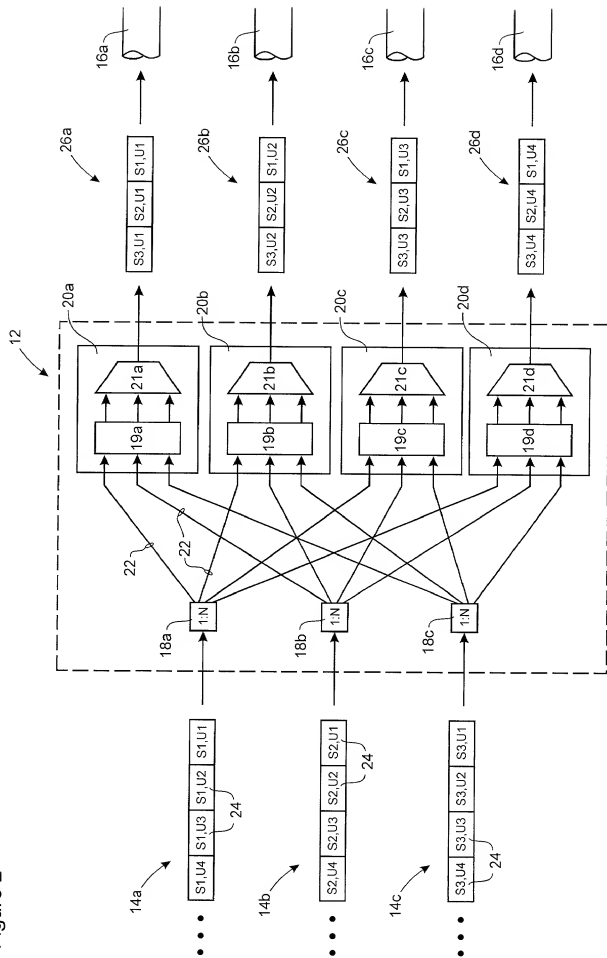
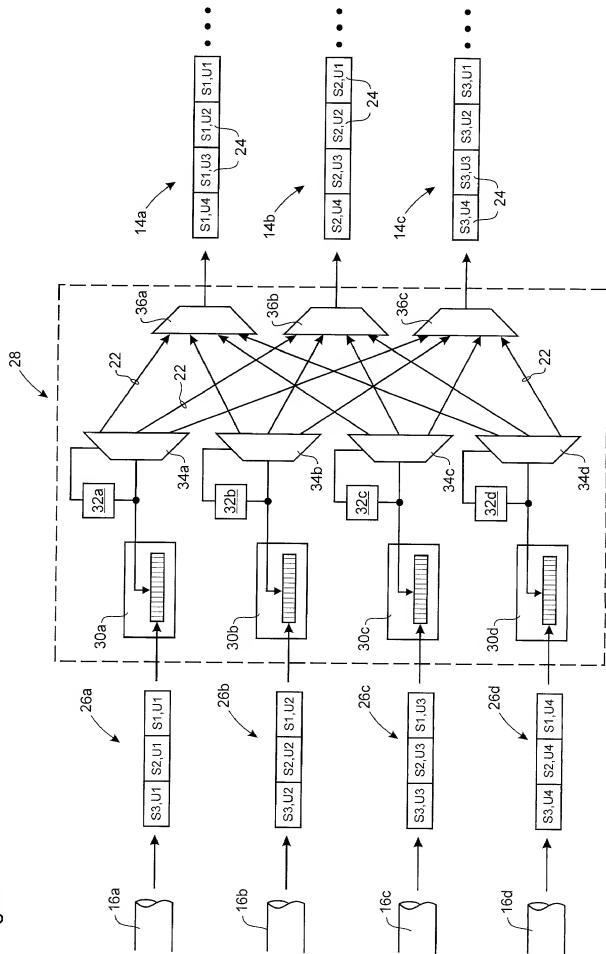


Figure 3



<b>COMBINED</b> <b>DECLARATION FOR UTILITY OR</b> <b>DESIGN</b> <b>PATENT APPLICATION (37 CFR 1.63)</b> <b>AND POWER OF ATTORNEY</b>		Attorney Docket Number <b>9-13528-131US</b> First Named Inventor <b>SMITH, Roland A.</b> <hr/> <i>Complete if known</i> Application Number <b>Not yet available</b> Filing Date <b>Filed concurrently herewith</b> Group Art Unit _____ Examiner Name _____
<input checked="" type="checkbox"/> Declaration Submitted with Initial Filing	OR <input type="checkbox"/> Declaration Submitted after Initial Filing <small>(surcharge (37 CFR 1.10(e)) required)</small>	

**As a below named inventor, I hereby declare that:**

My residence, post office address and citizenship are as stated below next to my name.

I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**METHOD AND APPARATUS FOR EQUALIZATION  
ACROSS PLURAL DATA CHANNELS**

the specification of which

☒ is attached hereto.

OR

☐ was filed on \_\_\_\_\_

(mm/dd/yyyy)

as United States Application Number or PCT International Application Number \_\_\_\_\_

and was amended on \_\_\_\_\_ (if applicable).

(mm/dd/yyyy)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not claimed	Certified Copy Attached?	
				YES	NO
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	<input type="checkbox"/> Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

**COMBINED DECLARATION FOR UTILITY OR DESIGN  
PATENT APPLICATION (37 CFR 1.63) AND POWER OF ATTORNEY**

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (if applicable)

☐ Additional U.S. or PCT International application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to transact all business in the Patent Trademark Office connected therewith:

☒ Customer Number: **20988**



**20988**

Direct all correspondence to:



**20988**

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

**Name of sole or First Inventor:**

☐ A petition has been filed for this unsigned inventor

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Inventor's Signature

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**DECLARATION**

**ADDITIONAL INVENTOR(S)**  
**Supplemental Sheet**  
**Page 1 of 1**

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Date

Residence:

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State

Country

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